Introduction

Magnetic minerals such as iron oxides (Liu and Liu, 1999) and iron sulphide ((Reynolds et al, 1991) have been shown to precipitate and/or alter due to hydrocarbon migration leading to the creation of unique magnetic signatures along hydrocarbon migration pathways (Abubakar 2016; Badejo 2019). Siderite, a paramagnetic mineral with Néel temperature of 37K (Frederichs et al. 2003) has also been found variously in hydrocarbon environments (Emmerton et al., 2012; Badejo, 2019) and may also be an authigenic product of hydrocarbon migration. However, siderite is a common authigenic cement found in sedimentary rocks. The conditions necessary for its formation include a reducing environment and available Fe$^{2+}$ and inorganic carbon (Machel and Burton 1991; Wilkinson et al. 2000; Larrasoaña et al. 2007) and these conditions can occur at shallow depths in the sulphate reduction zone and the methanogenesis zone, and in deeper methanic environments (Wilkinson et al. 2000; Larrasoaña et al. 2007; Roberts, 2015). Here, we show via magnetic experiments that siderite is precipitated as a results of hydrocarbon migration and propose a mechanism that is responsible for this process.

We carry out this study in the Catcher Area Development of West Central Shelf, UK North Sea. The Catcher Area Development (CAD) is about 180km ESE of Aberdeen and consist of at least six oilfields of excellent reservoir properties (Fig. 1a). Tay sandstones which are interpreted to be wholly to partially injected and Cromarty sandstones which are interpreted to occur as a spectrum from partially injected to unaltered constitutes these reservoirs (Roberts et al. 2017). Tay sands in the CAD were initially deposited in a discontinuous pattern along the slope accumulating only in areas with accommodation space such as the hanging wall of a Tertiary faults (Robertson et al., 2013). Fluids in CAD do not appear to be in communication as can inferred from the fluid distribution in the area supporting the lack of continuity of the sand bodies (Fig 1b). The hydrocarbons of the CAD which are trapped both stratigraphically and structurally, are of relatable properties suggesting a similar hydrocarbon source migrating along a fill-spill chain.

![Figure 1](image_url)

**Figure 1:** a) Regional map highlighting the distribution of Tay, Cromarty and Forties sandstone members in the Central North Sea and the Moray Firth basin (Modified from OGA release). The simplified stratigraphic column shows the lithostratigraphic nomenclature of Knox & Holloway (1992). The study area (Catcher Area Development and Gannet-Narwhal Channel) lies in the West Central Shelf of the UK Central North Sea and is highlighted using a blue polygon b) Well correlation of the Tay and Cromarty sandstone highlighting the hydrocarbon contacts/free water level and the cored section.
Method

Core of the Tay and Cromarty sands from the CAD and three neighbouring dry wells were sampled at BGS Corestore, Keyworth, Nottingham. Rock magnetic experiments were carried out on these samples to determine their magnetic susceptibility and minerology. Room-temperature hysteresis loops were measured for 71 and 11 core samples from six CAD wells and three dry wells respectively to gain insights on their saturation magnetization, remanence and coercivity distribution. These properties were measured while cycling these samples from a ‘saturating field’ of 500mT to -500mT. To identify the rock samples’ magnetic minerology, low temperature magnetometry (LTM) and high temperature susceptibility measurements (HTSM) were subsequently carried out on 24 and 17 CAD samples respectively, and 4 dry wells samples. The LTM together with HSTM enabled the detection of siderite in the sample.

Results

The high field slope of the hysteresis loops was used to characterize the samples based on their degree of paramagnetism. We categorized the samples as either strongly paramagnetic or weakly paramagnetic. For the CAD wells that exhibited both signatures, a regional divide generally existed between the strongly paramagnetic and weakly paramagnetic samples for each sand layer (see Fig 2). Only two samples were anomalous to this trend, one at the oil water contact and one ‘randomly’ situated. The oil water contact anomalies may be due to increases in the total dissolved sulphur (Machel 2001) which will react with available Fe$^{2+}$ to form iron sulphides at the expense of siderite (Wilkinson et al. 2000). The other sample sits at the marginal position between the two paramagnetic categories. The dry wells also contained both strongly paramagnetic and weakly paramagnetic samples.

![Figure 2](image)

**Figure 2**: Classification of the magnetic properties of the cored Tertiary sandstones from the Catcher area development based on their paramagnetic proportion. Gaps in the sequence indicate regions with interbedded mudstone. Note that the gaps are not draw to scale.

LTM and HTSM carried out on the strongly paramagnetic CAD samples identified the presence of siderite. This was confirmed using Mossbauer spectroscopy. Siderite was not identified in any of the weakly paramagnetic samples that underwent either LTM, HTSM or Mossbauer Spectroscopy. Siderite was also not identified in any of the dry well samples via LTM, HSTM or Mossbauer Spectroscopy. Note that LTM and HSTM was carried out on four dry well samples, two of which were strongly paramagnetic. Find example figures in Fig. 3.
Figure 3: Result of thermomagnetic experiments on a strongly-paramagnetic oil stained sample. LTM and HTSM suggest the presence of siderite (differences in magnetization values and joint of the ZFC (Zero-field cooled) and FC (Field-cooled) curves and rapid increase in magnetization susceptibility between 300°C and 530°C) in (a). These diagnostic signatures for siderite are absent in weakly paramagnetic samples.

Conclusions

Siderite is precipitated in the CAD as a result of the environment created by the presence of hydrocarbon. Siderite absence from the dry wells and its distribution in the CAD wells supports this inference. Siderite observed in shallow sediments are usually locally more abundant. Examples (Wilkinson et al., 2000; Antoshkina et al., 2017; Vuillemin et al., 2019). Furthermore, sand injection in the CAD which likely occurred between Oligocene-Miocene (Cartwright et al., 2003; Carruthers et al., 2013) will have distorted the stratigraphic setting of the parent sand body making the zonation of siderite formed pre-injection unlikely. 3D Basin modelling have shown that accumulation of hydrocarbon in West Central Shelf began in the Miocene (Badejo 2019) after sand injection and likely created the environment suitable for the precipitation of siderite. This zonation of siderite observed in CAD (as shown in figure 2) is likely due to the thermodynamic constraint on the precipitation of siderite in the presence of other reacting minerals.

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References


